

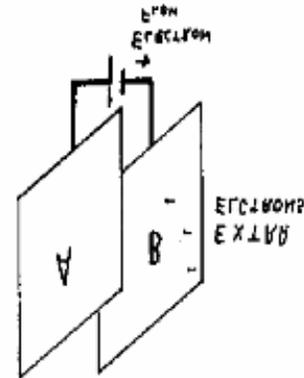
Passages in small print are for interest and need not be learnt for the R.A.E.

Capacitance

Consider two metal plates that are connected to a battery. The battery removes a few electrons from plate "A" leaving it positively charged and pushing them on to plate "B". Plate "B" is now negatively charged and repels so strongly that the current ceases. The plates, therefore, have a very small capacitance for the storage of electricity.

The plates are now brought as close as possible without actually touching. Electrons approaching plate "B" are still repelled by its negative charge but will also experience attraction from the positive "A" plate. The battery can now push many more electrons on to plate "B" so the plates have a much greater capacity for storing the charge.

This two plate device is called a capacitor and its capacitance is measured in Farads.



The Farad is the unit of capacitance. A capacitor has a capacitance of one Farad if, when charged by one Coulomb, has one Volt across its plates.

The energy stored in a capacitor = $1/2 \times CV^2$ Joules. (One (One Watt=One Joule per second)

The Farad is a very big unit so the following subdivisions are used in practise.

$$1 \text{ microfarad} = \frac{\text{Farad}}{\text{Million}} = 1\mu\text{F} \text{ or } 1 \times 10^{-6} \text{ Farads}$$

$$1 \text{ nanofarad} = \frac{\text{Farad}}{\text{Thousand million}} = 1\text{nF} \text{ or } 1 \times 10^{-9} \text{ Farads}$$

$$1 \text{ Pico farad} = \frac{\text{Farad}}{\text{Million million}} = 1\text{pF} \text{ or } 1 \times 10^{-12} \text{ Farads}$$

The capacitance of a capacitor is:

- proportional to the AREA of the plates
- inversely proportional to the DISTANCE between the plates
- proportional to the PERMITTIVITY of the dielectric between the plates

It is very important to have insulation (dielectric) between the plates that will stand up to the voltage that is to be used. Capacitors are usually marked with their safe working voltage. Ignoring this advice can be messy and explosive.

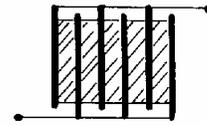
Permittivity

This is the goodness of the dielectric. Air has a value of 1. Other dielectric materials are compared with air.

Air	= 1	For example. A 10 pF paper
Dry paper	= 2.5	insulated capacitor would
Glass	= 5	become 20 pF of the dielectric
Mica	= 7	is changed to glass.

A Capacitor

A capacitor consists of at least two conducting plates separated by insulation. This insulation, which is often air, is called the dielectric. (Shown shaded) When a voltage is connected the plates take up the charge and are able to store a quantity of electricity.



Current only flows when the capacitor is actually charging or discharging. The charging current is initially quite high but gradually reduces to zero as the voltage across the capacitor rises to equal the supply voltage.

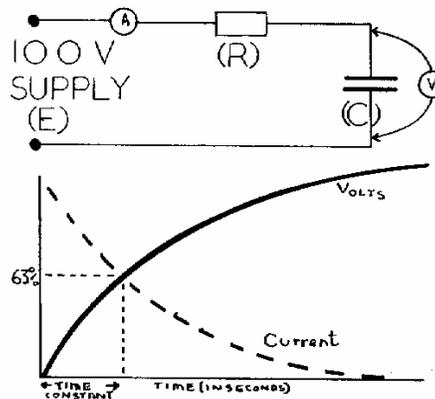
The amount of electricity stored in a capacitor is measured in Coulombs. Assuming no losses, this charge will remain in the capacitor after the Supply voltage has been removed.

Take care when handling high voltage capacitors!

$$\begin{array}{cccc} \text{QUANTITY OF ELECTRICITY} & = & \text{CAPACITANCE} & \times & \text{VOLTAGE} \\ \text{(Coulombs)} & & \text{(Farads)} & & \text{(Volts)} & & \text{(Q=CV)} \\ Q & & C & & V & & \end{array}$$

This circuit shows a capacitor (C) being charged via a resistor (R). This constitutes a "time constant" circuit.

The time constant (in seconds), of a CR circuit is the time taken for the voltage across the capacitor to reach 63% of the supply voltage.



The graph shows both the current and the voltage as the capacitor charges via R.

$$\begin{array}{ccc} \text{Time constant} & = & \text{Capacitance} \times \text{Resistance} \\ \text{(Seconds)} & & \text{(Farads)} \quad \text{(Ohms)} \end{array}$$

Capacitors connected in Parallel

The capacitance of a capacitor is proportional to the area of its plates. Increasing the area of the plates will increase the capacitance. Connecting two or more capacitors in parallel is equivalent to a single capacitor with larger plates.

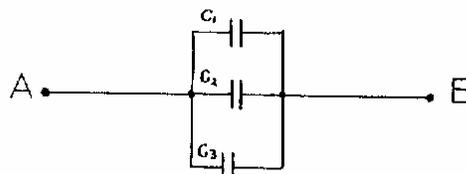
The resultant (Ct) of capacitors connected in parallel is the sum of the individual capacitors. $C_t = C_1 + C_2 + C_3$ etc

You will notice that the formula for Capacitors in parallel is similar to The formula for resistors in series.

Example.

What is the total capacitance between A and B ?

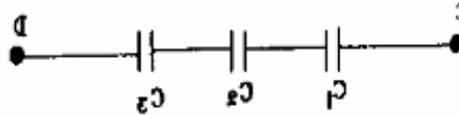
$$\begin{array}{l} C_t = C_1 + C_2 + C_3 \\ C_t = 8 + 12 + 24 \text{ pF} \\ C_t = 44 \text{ pF} \\ \text{(Ct stands for} \\ \text{"total capacitance")} \end{array}$$



Capacitors in Series

When capacitors are connected in *series* it is the same as *increasing* the distance between the plates. Thus, when capacitors are connected in series, the total capacitance will be less than any of the individual capacitors. The resultant capacitance of capacitors connected in series is the *reciprocal sum*. In other words, the formula is like the one used for resistors connected in parallel.

$$\frac{1}{C_t} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} \text{ etc}$$



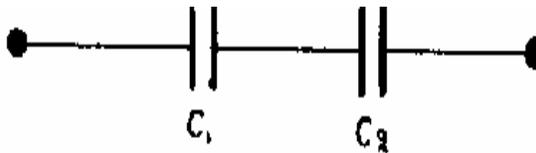
Example: What is the total capacitance between C and D ?

$$\frac{1}{C_t} = \frac{1}{8} + \frac{1}{24} + \frac{1}{12} = \frac{3+2+1}{24} = \frac{6}{24}$$

Therefore $C_t = 24/6 = 4\text{pF}$

If only two capacitors are connected in series, there is a simpler formula That can be used.

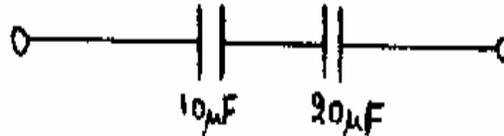
$$C_t = \frac{C_1 \times C_2}{C_1 + C_2}$$



Example:

What is the total capacitance when a 10 μF capacitor is connected in series with a 20 μF capacitor ?

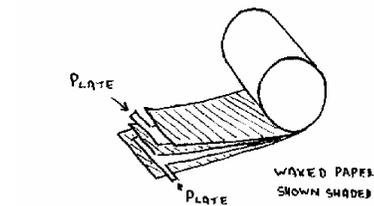
$$C_t = \frac{10\mu\text{F} \times 20\mu\text{F}}{10\mu\text{F} + 20\mu\text{F}} = \frac{200\mu\text{F}}{30\mu\text{F}} = 6.6 \mu\text{F}$$



Construction of Capacitors

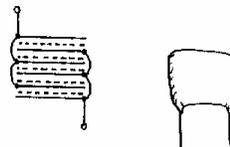
Paper Capacitors

These are made from a "sandwich" of strips of foil and wax impregnated paper. Of course, capacitors need two plates, so two such sandwiches are put on top of one another and then rolled up together. The foil forms the plates and the waxed paper is the dielectric.



Mica Capacitor

Mica stacked capacitors are made up of alternate layers of thin metal sheet and thin layers of mica. Odd metal sheets are connected together to form one plate and the even ones connected together to form the other.

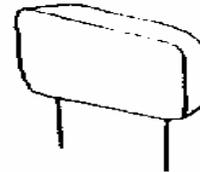


Silvered Mica

Silver is sprayed on the sheets of mica to form the plates. It is possible to make these capacitors very accurately. The value of the capacitance changes very little with wide temperature changes thus making them very suitable for the tuned circuits in oscillators.

**Ceramic Capacitors**

These consist of small pieces of ceramic that have a coating of silver on each side. Ceramic capacitors are suitable for de-coupling but should not be used in tuned circuits owing to the large capacitance variations with changes of temperature.

**Electrolytic Capacitors**

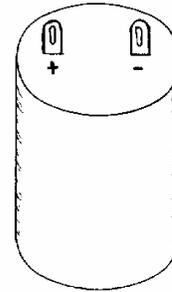
Electrolytic Capacitors can be manufactured with very high capacitance for their size.

They consist of two aluminium foil strips interleaved with an absorbent paper strip and wound very tightly into a cylinder. The paper is impregnated with an electrolyte. A voltage is applied and a dielectric layer of aluminium oxide is formed on the foil that is connected to the positive supply.

Thus one capacitor plate is one of the foil strips and the other plate is the electrolyte itself with the oxide acting as the insulating dielectric. This is the clue to the high capacitance. Remember that the closer the plates the higher is the capacitance. The oxide film is extremely thin.

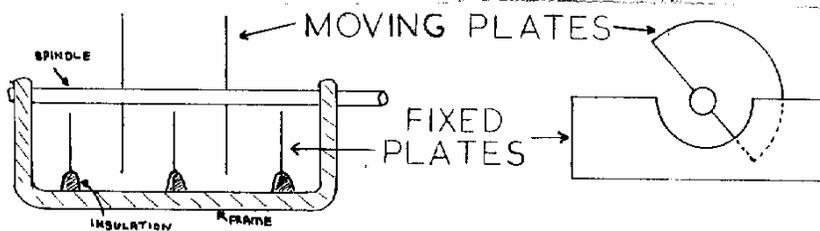
The second foil strip purely acts as a means of connecting to the electrolyte.

It is very important to ensure that electrolytic capacitors are connected right way round in any circuit.

**Variable Capacitors** (sometimes called "tuning capacitor")

These have one set of fixed plates and one set of moving plates. The dielectric is usually air. The moving plates are connected to the frame of the capacitor, thus avoiding the need for insulated pivots. The fixed plates mounted on insulators.

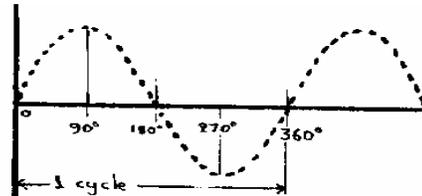
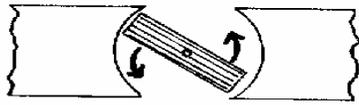
When the plates are rotated the overlap, and hence the capacitance, changes.



Alternating Current (A.C.)

Remember that when a current is passed through a coil in a magnetic field, A force acts on the coil to try and make it turn. (Fleming's Left Hand Rule)
 The opposite is also true. IE If a conductor is moved through a magnetic field an electric current will be generated. (Fleming's Right Hand Rule)
 A generator has a coil that continues to rotate in the same direction. The wires of the coil continually pass 'to and fro' through the magnetic field. This produces electricity that flows in one direction for half a revolution and reverses in the next half cycle.. and so on.

The current and voltage produced are *sine wave* in shape.



Frequency

Frequency

The number of times that the waveform repeats itself each second is known as the frequency. HERTZ is the unit of frequency and is the number of complete cycles that occur in one second.

The height of a waveform is called its *amplitude*. True alternating current is centred over a zero line. Thus, the portion of the waveform above this line is positive and that below the line is negative. Alternating current therefore comprises a series of Pos & Neg half cycles.

A.C. Amplitude Measurements

The PEAK value of a waveform is the maximum POS or NEG value.

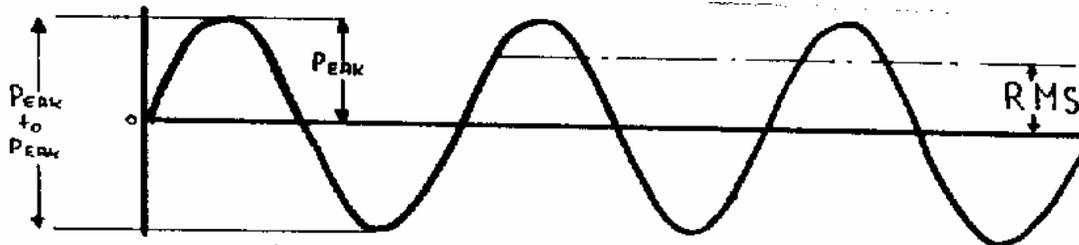
The PEAK TO PEAK value is the difference between the max Pos and max Neg value. It is normally twice the peak value.

RMS. In A.C. the value is continually changing from a max, through zero and back to a max in the opposite direction. This means that there will not be so much power present as there would be in direct current equal to the peak value.

The RMS (root mean square) is the equivalent D.C. current or voltage that would produce the same heating effect as the A.C. waveform.

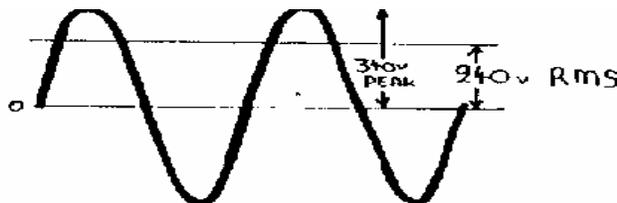
This assumes the waveform is a sine wave.

Example: The mains supply has an RMS voltage of 240 Volts.



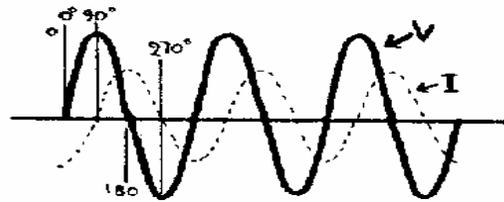
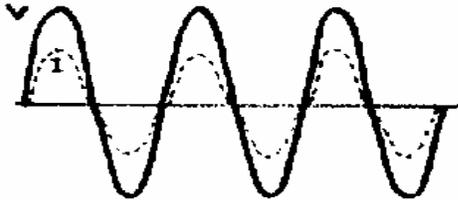
Its peak value is $RMS \times 1.414 = 340$ Volts.

Most meters are calibrated to indicate RMS values.



Phase

It is possible to have two waveforms that have the same frequency but start at different times. These waveforms are said to be out of phase. The phase difference is measured in degrees. The waveforms below show an example of current and voltage being "in phase".



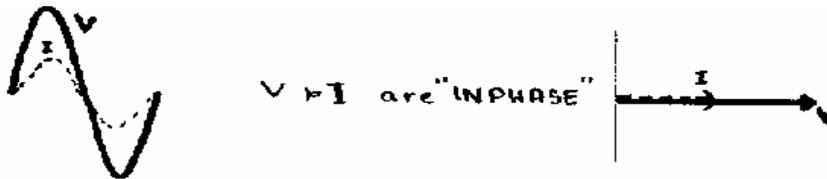
The above, shows the current lagging the voltage by 90°. This is the same as saying that the voltage leads the current by 90°

A bit about Vectors

In-phase and out-of-phase waveforms can be shown using simple vectors. The vector can represent both the amplitude and the phase angle. The angular rotation always goes anti-clockwise starting from 3 o'clock (doesn't work if yours is digital'.). This sounds rather complicated - it will become clearer when shown in action

A.C. circuits

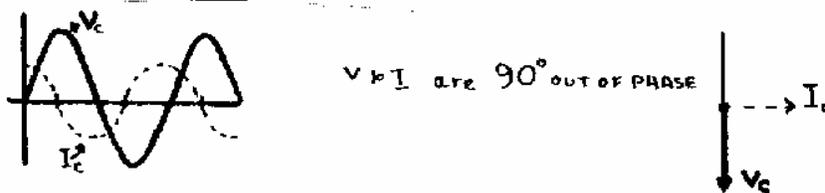
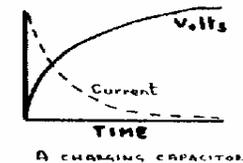
Ohms Law can, quite simply, be applied to alternating waveforms if the circuit only contains resistance. The values can be either RMS or peak but they must never be mixed. In an A.C. circuit containing only resistance the current flowing will be in phase with the applied voltage. This can be shown graphically or vectorally.



Capacitance

Remember that when a voltage is applied to a capacitor the initial charge current is high at a time when the voltage is small. However, when the voltage has reached its maximum value the current will be very small. When this is applied to A.C. through the capacitor will be 90° ahead of the voltage. This is usually stated as follows:

In a capacitive circuit the current LEADS the voltage by 90°. This can also be stated the other way round: In a capacitive circuit the voltage LAGS the current by 90°. This is shown below by graphs and vectors



You will see that the current is zero when the voltage is a maximum.

This means that application of the usual power formula ($W=V \times I$) will result in zero Watts. This current is known as a *reactive current*

A.C "resistance" of a capacitor.

This is known as the reactance of a capacitor and is measured in Ohms. Capacitive reactance depends on both the value of the capacitor (Farads) and the frequency (angular rotation ω) of the alternating current.

The angular rotation (ω) is $2 \times \pi \times$ frequency and is used in most of the A.C. calculations. (π is pronounced "pie" and is 3.142)

Reactance is given the symbol "X". It is usually followed by a small L or C to indicate either inductive or capacitive reactance.

$$\text{Capacitive Reactance } (X_C) = \frac{1}{\omega C} = \frac{1}{2\pi f C} \quad (\text{Remember } \omega = 2\pi f)$$

EXAMPLE

What is the reactance of a 2 μ F capacitor at 50 Hz and at 50 kHz ?

First, remember that the capacitance must be converted to the basic Farad.

IE: $\mu\text{F} = 1 \times 10^{-6}$ Farads

At 50Hz $\omega = 2 \times \pi \times 50$

$$X_C = \frac{1}{\omega C} = \frac{1 \times 10^6}{2 \times \pi \times 50 \times 2} = \frac{10000}{2\pi} = 1592\Omega$$

At 50kHz $\omega = 2\pi \times 50000$

$$X_C = \frac{1}{\omega C} = \frac{1 \times 10^6}{2 \times \pi \times 50000 \times 2} = \frac{10}{2\pi} = 1.592\Omega$$

The above examples show that reactance changes dramatically with a change in frequency. If further values were taken and plotted on graph paper it would look like this:



As the frequency INCREASES the Capacitive Reactance DECREASES.

The alternating current flowing through the capacitor can be calculated Using the "reactive" version of Ohms Law:

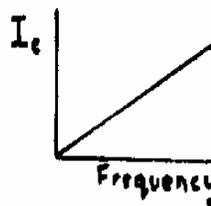
$$I = \frac{V}{X_C} \text{ Amps}$$



At 50Hz $I = 4/1592 = 0.00251$ Amps
(2.51mA)

At 50kHz $I = 4/1.592 = 2.51$ Amps

This graph shows the relationship between the 'current flowing through a capacitor' and 'frequency'.



Don't give up

Most people find this lesson (and 4A) rather tricky - you are not alone. Don't spend so much time on it that you actually grind to a halt!

QUESTIONS FOR LESSON 4

[Some question numbers are omitted - this is correct]

QUESTION: 4.2 What is the reactance of a 100 pF capacitor at 50 Hz?
What is its reactance if the frequency is raised to 200 kHz ?

QUESTION: 4.3 A mains supply has a peak voltage of 300 Volts.
What value would an RMS voltmeter indicate ?

QUESTION: 4.6 Describe an air spaced tuning capacitor.

QUESTION: 4.12 A four microfarad capacitor and a six microfarad capacitor are connected in series. What is the resultant capacitance ?

QUESTION: 4.14 Two 8 μF capacitors are connected in parallel.
What is their total capacitance ?

- A) 64 μF B) 8 μF C) 16 μF 1)) 4 μF

QUESTION: 4.15 Two waveforms (of the same frequency) are completely out of phase. Their phase difference is therefore said to be:-

- A) 180° B) 90° C) 270° D) 360°

QUESTION: 4.16 A 50Hz, 10 Volt (RMS) A.C. supply is connected across a 20 Ohm resistor. What RMS value of alternating current will flow?

?

- A) 1.414 Amps B) 0.353 Amps C) 2.0 Amps D) 0.5 Amps

QUESTION: 4.17 A 1 μF capacitor is charged from a 10 Volt DC supply via a 10 kOhm resistor. How long will it take the voltage across the capacitor to reach 6.3 Volts ?

QUESTION: 4.18 A 100 pF capacitor has mica dielectric.
What would be the capacitance be if the mica were replaced with glass ?

A bit of help with some maths

An appendix attached to this lesson will give some help for calculations in AC theory

Maths appendix**Indices**

Q^2 means 'Q squared', in other words Q times Q (IE $Q \times Q$).

Q^3 is Q cubed or $Q \times Q \times Q$

If Q has a value of 10 then $Q^2 = 10 \times 10 = 100$ and $Q^3 = 1000$

This idea can be helpful when working with very large or small numbers. One million (1000000) can be rewritten as 10^6 .

This is 'shorthand' for $10 \times 10 \times 10 \times 10 \times 10 \times 10$

Three million, five hundred thousand (3500000) = 3.5×10^6

Another example:

The speed of light is 300 Million or 300×10^6 Metres per second.

300 can also be written as 3×100 or 3×10^2 so this speed can also be expressed as $3 \times 10^2 \times 10^6$ Metres per sec.

Note that $10^2 \times 10^6 = 10^8$ or $100 \times 1000000 = 100,000000$

This example gives a clue to an important rule concerning these little Numbers called 'indices'.

To multiply: add the indices

$$10^2 \times 10^4 = 10^{(2+4)} = 10^6$$

The rule for division involve subtraction of the indices.

To divide: subtract the indices

$$\frac{100000}{100} \text{ is } \frac{10^5}{10^2} = 10^{(5-2)} = 10^3 \text{ or } 1000$$

$$\text{Now look at } \frac{100}{10000} \text{ This is } \frac{10^2}{10^4} = 10^{(2-4)} = 10^{-2}$$

Moving the decimal point

Take 10.00 Moving the decimal point one place to the right gives 100.0 In other words, ten times bigger.

Now take 543.21 Moving the decimal point two places to the left Gives 5.4321 This is one hundredth of the original number.

$$1 \times 10^{-2} \text{ is the same as } \frac{1}{10^2} \text{ and this is } \frac{1}{100}$$

An G4EGQ tip!

Add extra zeros, if necessary, for the decimal point to jump over.

They can be put both before (called 'leading') or after ('trailing')

If you are not sure if the next move is to be multiplication or is to be division.

Add extra zeros to 1×10^{-2} gives 0001.000×10^{-2}

Move decimal point one place to the left: 000.1000×10^{-1}

Move it one more place to the left: 00.01000×10^0

(10^0 is equal to 1)